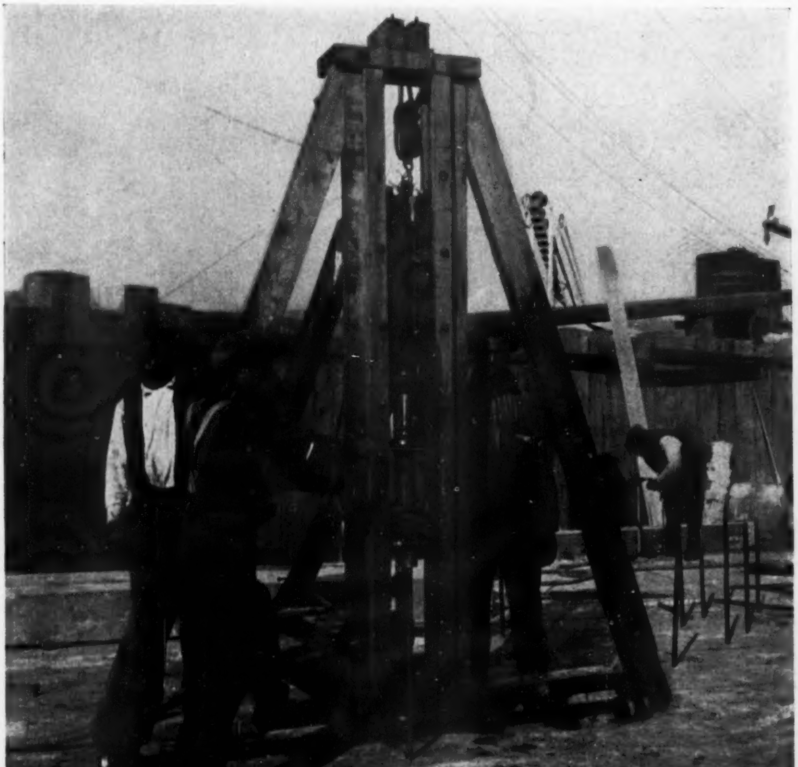
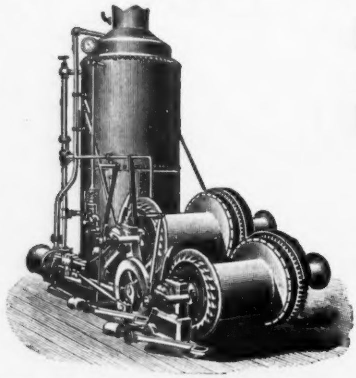
Compressed Air

DEVOTED TO THE USEFUL APPLICATION OF COMPRESSED AIR.

VOL. III. NEW YORK, FEBRUARY, 1899. No. 12



DRIVING DRIFT PINS BY A COMPRESSED AIR DEVICE. WOOD BORING MACHINE IN THE DISTANCE.



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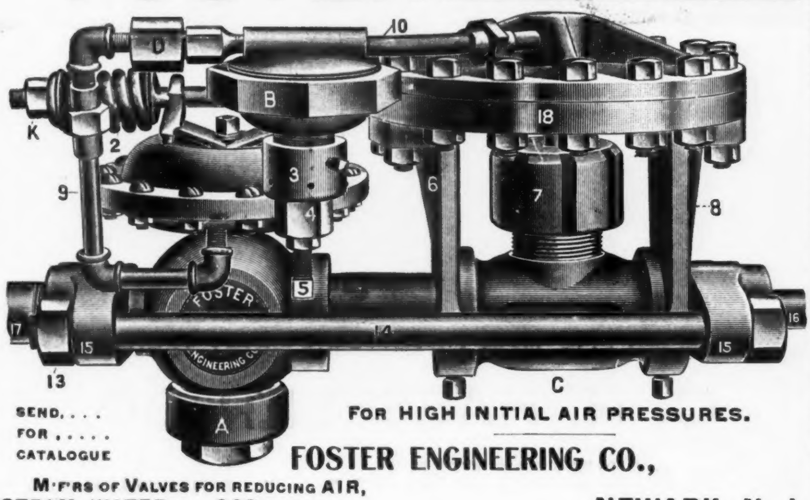

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Compressed Air.

A MONTHLY PUBLICATION DEVOTED TO THE USEFUL APPLICATION OF COMPRESSED AIR.

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Facts in regard to Air Power and Auto-Truck Companies.

During the past two weeks a great deal of publicity has been given to the various companies which have been organized by persons directly interested in Hoadley-Knight Compressed Air appliances. Messrs. Hoadley-Knight have patented Motors for operating Street Cars, Carriages, and Trucks.

In the early part of last year The American Air Power Company was formed by the combination of the Hoadley-Knight and Hardie Companies. Capital $7,000,000. Its president is Mr. A. A. McLeod, formerly President of the Reading Railway, and its directors are William L. Elkins, Thomas Dolan, Thomas Ryan, Joseph H. Hoadley, and A. A. McLeod. Its relations with the Metropolitan Street Railway Company are very close.

Arrangements have been made by the American Air Power Co. with the Metropolitan Street Railway Company allowing the equipment of the 28th and 29th Sts. crosstown lines in New York with cars having improved air motors. The work of installing the plant at 24th St. and 13th Ave. for that purpose is now progressing rapidly. The Air Compressor and twenty cars are nearly completed.

Messrs. Hoadley-Knight are also interested in what is known as the Auto-Truck. Imbued with the idea that this Truck answers all the requirements of Automobile traction, another company has been formed for the purpose of devoloping the Auto-Truck. The Hoadley-Knight Truck was fully described in the December, 1898, number of "Compressed Air," showing a truck as constructed, and used in the works of the Am. Wheelock Engine Co., Worcester, Mass.

The Company known as the New York Auto-Truck Company was organized under the laws of New Jersey and capitalized at $10,000,000. Its incorporators are Richard Croker, Nathan Straus, Lewis Nixon, Robert I. McKinstry, Senator Arthur P. Gorman, Joseph H. Hoadley.

Still another Company has been recently organized under the auspices of Messrs. Joseph H. Hoadley, William E. Knight, Harry E. Knight, Robert I. McKinstry and Edwin F. Glenn, known as the International Air Power Co., with capital stock $7,000,000. The purpose of this Company is to operate in foreign countries under patents similar to those assigned to the American Air Power Company and the New York Auto-Truck Company, the Hoadley-Knight foreign patents on pneumatic traction not having been assigned to the American Air Power Co. The daily papers of New York and elsewhere have given wide circulation to the plans of the movers in these compressed air enterprises, and the impetus thus created has provoked numberless inquiries as to the feasibility of the published claims.

All that can be said at this writing is that the avidity of the newspapers is responsible for many of the assertions that lack the stability necessary to useful results; at the same time the publicity has produced a healthy consideration of compressed air.

Economies in the use of Compressed Air.

An Inlet Cooler which Saved Five Per Cent. — Suggestions Regarding the Suction Valve Chamber — Staging and Intercooling, and How the Latter Might Be Improved.

ADVANTAGES OF COMPRESSED AIR OVER OTHER SOURCES OF POWER IN DEEP MINING—GREAT DEVELOPMENTS PREDICTED.

By R. P. Whitelaw.*

It seems strange that although compressed air has been used chiefly in mines for hoisting, pumping, coal cutting, and various devices for the last 50 years, little or nothing has been done towards making it an economical method—whether on account of the difficulties which have presented themselves in the form of heat or cold, or a general indifference to its use, I am not in a position to say—but I am inclined to think it is the latter, as our greatest engineers and experimenters have lived during that period; and had they devoted the same attention to this subject as they have given to steam and electricity, compressed air would stand on a much higher level than it does to-day, and there would be but little use for electricity.

In about the year 1849 an air compressor plant was installed in Glasgow for driving an underground air hoist; the compressor, I might say, was a fast running one, and but little attention was given to cooling devices, and the result was that it had not run many hours before the cylinders and pipes close to the compressor were red hot; in fact, the engineer thought they would melt, and then the report came up from below that the engine had frozen up; this was thought to be a great phenomenon, and was talked about all over the country. The freezing was caused by over-expansion, and yet the difficulty was got over without changing the ratio—by injecting a spray of water into the compressor cylinder the temperature was reduced to such an extent that there was no difficulty in running the compressor. The moisture thus injected was then carried over to the hoist and prevented the freezing up of the exhaust ports. Had the air been dry in the first instance (I might say there is no such thing as dry air) freezing up could not have taken place, and yet it was prevented by still adding more water to it. This may seem strange, yet it was so; for air with a high percentage of water has a much higher specific heat value than dry air, so that in the first place it is more difficult to heat, and in the second it is more difficult to cool. In round numbers, dry air at 140 deg. F. initial temperature, with a ratio expansion of 2, is reduced to 32 deg. F., whilst moist air with the same initial temperature is only reduced to 32 deg. F. after four expansions. The same applies to the compression of air. Atmospheric air at 68 deg. F. initial temperature, when compressed to 100 lbs. pressure, rises, if dry, without cooling to 490 deg. F., and if sufficiently moist to 194 deg. F. only.

The practice of injecting water into the compressor cylinder is being carried out to the present day in some of the Scotch collieries, and so long as it will run their engines they are satisfied, and the difficulty for them is ended; a few tons of coal per week is of no importance in their calculations; thus compressed air is, by Scotch coal owners and by many other users, left to work out its own salvation. It is wasteful even to the extent of 50 to 60 per cent., and we only use it where we cannot use steam; that is how compressed air is abused, and I really think there are more abusers than users of it.

When the air is compressed all the work which is done in the compression is converted into heat, and from this it would seem that as soon as all the heat has been got rid of the work done on the air is virtually thrown away, and the air will have not more energy than it had before compression if the temperature is not increased. It is quite true that it has no more energy than it had before compression, but the advantage lies in bringing it into a more available form. The heat of compression increases the volume, and it is, therefore, necessary to have a much larger compressor than if no heat was generated. The first cause of loss of work then is theoretically unavoidable, but then theory and practice are very different things, more especially in air com-

* Paper read before the Mechanical Engineers' Association of South Africa.

pression—for instance, theory says that time plays no part in the heating of air during compression, whilst practice says the faster you run your compressor the higher the temperature will rise. That is quite true, but in the first instance the heat is lost by radiation, whilst in the second case we cannot lose it as it has not time to get away, and this is the task we have to set ourselves to—viz., to get rid of the heat during the compression, or, if possible, before compression.

All makers of compressors in giving instructions how to use these machines advise taking the air from the cool or shaded side of the engine-room, so that the air will enter the compressor as cool as possible, and, therefore, it will occupy a smaller space and be so much cooler when compressed. You must bear in mind that every 5 deg. F. you reduce it in this way means 1 per cent. saving. Now the question arises, can this cooling before entering the compressor be extended beyond taking the air from the cool side of the house? It can, and the following method I tried at the Pearl Central with a new Riedler air compressor that had the advantage of two inlets to the suction valve chambers, one opening to the engine-room and the other could be led under the floor. The latter was carried down about 10 ft., and then a drive was cut from there to a distance of about 40 ft., then a shaft was driven down to meet this. An old chimney was put down the shaft and on top of the chimney there was fixed a large spray about 3 ft. in diameter—very little water was used to keep a decent shower going all the time, and the water not only cooled the air, but washed away all the dust. The results got from this were more than I expected, as the air was cooled 15 deg. F., showing a saving of about 3 per cent., and the engine-room temperature was 10 deg. F. higher than the outside air, so that I have a right to claim 25 deg. F. of cooling, or effecting a saving of 5 per cent. over taking the air from the warm room. The result was excellent, as the cost of installing the cooler was very small. The inlet cooler could be still further improved upon by having a fan blast to blow along the tunnel, and if compressed air was used anywhere close by for driving a pump or a hammer it could also be exhausted into the tunnel; so you will see that it is possible to effect a further cooling of about 10 deg. F. to 12 deg. F.

Another point that ought to be attended to is the suction valve chamber. With some compressors nothing can be done, but in the present Reidler the arrangement is simply splendid for having a trickling cooler keeping the chamber cool, as working at present the suction chamber is nearly as hot as any part of the machine, and the result is that the air in passing takes up a considerable amount of the heat from the walls, and is expanded just on the point of entering the cylinder. The degree the air is heated at this point cannot be arrived at, but it is just possible that it is something like 20 deg. F. If it were only possible to prevent 10 deg. F. of this amount it would mean that another 2 per cent. added to the 5 per cent. we arrived at previously would make in all a saving of 7 per cent., which is a large item where 500 or 600 horse-power is being developed for making compressed air on a plant such as I have made mention of, or, in other words, on a 45-drill plant it would mean a saving in round numbers of £46 per month.

Having done all we can for a single stage compressor, little else can be accomplished unless by injecting a spray of water into the air while it is being compressed. To do this properly it would require an arrangement of tappet valves so as to give it the spray at the right moment. If this arrangement was well carried out I believe most excellent results would be obtained. The entrained water would be liberated as soon as the temperature dropped sufficiently and could be then trapped with an ordinary steam trap.

Jacket cooling is practically of no service except in assisting lubrication of the cylinder, so that little can be gained by jacketing the cylinder and heads and piston, as only a thin layer of the air that comes in contact with the metal surfaces is cooled.

We now come to the staging of the air. This has been the means of already reducing the cost of compressed air by about 20 per cent. Now, what does staging do after all? Well, it simply draws away the heat from the air whilst it is being compressed, and this we have already decided is the great difficulty we have to overcome. Suppose, for instance, air is compressed by an indefinite number of stages, and that each time the air is cooled to free air temperature, what do we attain? Very nearly isothermal

compression, and this is what we want to attain so that no loss will take place after the air has left the compressor. The gain is twofold: first, less power is developed; and, secondly, the air is delivered cold, and will, therefore, have no loss due to reduction in volume, which is the bugbear of compressed air as used at present.

Air expands and contracts as its absolute temperature. For instance, we have two compressors, one a single stage and the other a double stage. The other is delivering air at 500 deg. F., and the latter 200 deg. F., or say 961 deg. and 661 deg. F. absolute. The relative efficiencies are as 961 deg. is to 661 deg., or the latter has an advantage over the former of 24 per cent. So that I hope you will agree with me that staging and efficient inter-cooling are what is required to elevate compressed air to a first place for the transmission of power.

Inter-cooling between stages, as carried out at present in many cases, is far from perfect. Inter-coolers are made after the same form as feedwater heaters or condensers with a great number of tubes which are very liable to leakage. The tubes get coated with lime and other matters, which considerably reduce their efficiency. The best result that I know of is a reduction of temperature of from 200 deg. F. to 140 deg. F., while the air, to give full value, should be reduced to at least 72 deg. F., or free air temperature, I think a method could be adopted whereby the air could be reduced to free air temperature, and a really simple method, too. I find that air delivered from a single stage air compressor at a temperature of 470 deg. F. has been reduced to free air temperature before it has traveled 250 ft. through the delivery pipe. This is one of the great drawbacks to the use of compressed air; it is a decided disadvantage, but it might be taken advantage of for inter-cooling. What could be more simple for an inter-cooler than 200 ft. of pipes, even if it were 20 or 30 per cent. larger than is actually required? It would be much cheaper in the first place than the ordinary inter-cooler, if it was well laid down in the first instance—there is no reason why it should be looked at again, it would require no circulating water, if it was made large enough there would be no loss due to friction—it is a natural process, whilst the other is artificial. Any one of you can have a practical demonstration of it by fixing a thermometer to the air main. The pipe should not be buried into the ground, as earth is a good non-conductor of heat, and would give back heat to the air. It should be exposed to the atmosphere, and placed where it would get a free current of air, and should not be exposed to the sun. The present inter-cooler, as I have already mentioned, reduces the temperature to 140 deg. F., which I think is one of the best results that can be obtained, whilst the inter-cooler, already suggested, would reduce the temperature to say, at the very least, 70 deg. F., or a saving of 14 per cent. over the present system of inter-cooling. The figures I have just given refer to second stage compression, where the air is first compressed to 25 lbs. pressure and from 25 lbs. direct to 80 lbs. with a temperature of about 280 deg. F., from which temperature it is generally reduced to 70 deg. F., a drop of 210, showing a loss of exactly 28 per cent. from the time it leaves the compressor till the time it reaches the drills. The above figures work out as follows:—280 gives 741 absolute, 70 gives 531, and 741 : 531 : : 100 : 71.6, showing a difference on the wrong side of 28.6 per cent.—which is the actual percentage of loss. This is where better inter-cooling would give the advantage if the air was delivered at 70 deg. F. less, or 210 deg. F., the actual loss would only be 20 per cent. The remedies for this are three stage compression and reheating.

First, let us take three stages, and say the second stage raises the pressure from 25 lbs. to 60 lbs., and the temperature to 120 deg. F., and is again cooled down to free air temperature. It is well known that the temperature rises more rapidly in the early stages of compression than it does in the latter stages. For instance, from atmospheric temperature to 25 lbs. gauge it is raised from 80 to 290 deg., or an increase of 212 deg. F., whilst from 25 to 80 lbs. it is raised from 135 to 276 deg., an increase of 141 deg. In the first case the pressure is only increased 25 lbs., and in the second case the pressure is increased 55 lbs. This, I should say, speaks well for three stage air compression. The initial cost of such a compressor would certainly be much greater, but that would soon be made up in the increased economy. The temperature, as I have already pointed out, by compressing from 25 to 60 deg. would be 120 deg. F. The air is

then cooled to free air temperature and is sent on its last journey to 80 lbs.; the temperature would then be increased to about 110 deg. F., and this would be its final temperature. It has then only a drop of 40 deg. F. until it reaches free air temperature. The loss sustained by this fall in the temperature would then only represent 7 per cent., against a loss of 28 per cent. with a two stage air compressor, showing a gain of 21 per cent. in favor of three stage air compression over two stages.

The cost of such a machine would be much greater than a two stage compressor, so is a triple expansion engine a great deal more expensive than a compound, but still they are being extensively used, and why? Because the economy in running soon makes up for any extra initial cost. The same argument applies to three stage air compression.

I think it would be unfair of me to conclude my paper without touching on reheating, which is a very important factor in the use of compressed air. It is argued by many prominent engineers that the reheating of air for use in rock drills is a very difficult matter. More difficult problems than this have presented themselves to the engineering world and have been mastered, so also will the reheating of air for use in rock drills. Air at a low temperature has very little cooling effect upon water or other bodies it comes in contact with. The application of this, inversely applied, is of great advantage in the use of compressed air for the transmission of power, or, in other words, it requires but very little heat to raise the temperature rapidly; in fact, there is no other source of energy to which heat can be applied with the same economical results.

It is well known that after the transmission of compressed air to the point where it is to be employed a considerable saving of cost can be effected by reheating immediately before using. It can be easily shown that where air has been compressed to a certain pressure, and has by transmission to any reasonable distance been reduced to its normal temperature, if the air is reheated and expanded the extra volume resulting from the expansion is produced by an expenditure of heat much less than the original volume was produced for. Let us assume, then, for the sake of easy computation, that air is being compressed to 75 lbs. by steam at the same pressure, and that 2 cubic feet of steam are required for the production of 1 cubic foot of air, the weight of 1 cubic foot of steam at 75 lbs. is .208 lbs., and the total units of heat in 1 lb. of steam at 75 lbs. are 1151, therefore, the total units of heat in 1 cubic foot of steam are, in round numbers, 239. To produce 1 cubic foot of air at 75 lbs. will be required 239x2 B.T.U., or 478 B.T.U. As air at constant pressure expands or contracts at its absolute temperature, it is easy to show the quantity of heat required to double the volume of air at any temperature. We will again assume that we have got 1 cubic foot of air at 75 lbs. pressure and at 60 deg. F., or an absolute temperature of 521 deg. To double the volume we require to double the absolute temperature or, 521x21042, deducting from this 461 would leave the temperature by thermometric measurement to be 581, showing an increase of temperature of 581—60, or 521 deg. F. The specific heat of air at a constant pressure is .237, or nearly a quarter of the specific heat of water. The weight of 1 cubic foot of air at 75 lbs. pressure is .456 lbs., the actual heat expended, then, in doubling the original cubic foot of air at 60 deg. F. is 521, the temperature x.237, the specific heat x.457, the weight in lbs.—or 56.3 B.T.U., or as nearly as possible, 12 per cent. of what it took in heat units to produce it in the first instance. Of course, we cannot expect to get a reheater that will give the full heat value of the coal, but it is quite reasonable to expect at least 70 per cent. efficiency from the coal, which can be easily got from a good steam boiler with suitable coal. This would work out at 20 per cent. of the original cost of the air to exactly double the volume—such a result as this could not be got at in actual practice. The temperature—viz., 581 deg. F., is too high, and, again, it is not possible to produce air at 60 deg. F. without such a series of staging and inter-cooling that it would make the process of air compression too difficult. Anyhow, with two stage air compression air can be produced at 280 deg. F. Suppose it is then reduced to 60 deg. F. by transmission and storage, the loss incurred is 30 per cent., due to contraction in volume. We would, therefore, require 50 per cent. of the original heat units to double the volume of the air. I do not mean to say that even such a good result as that could be obtained, but I

do say this, that it is the duty of all engineers to do their utmost to endeavor to get as near to it as possible and raise to its proper level the most natural source of energy that exists in nature.

The reheating of air also makes it possible to use it expansively without fear of freezing up the exhaust ports; in fact, the temperature could be regulated to suit any reasonable cut-off, so that the temperature would not fall below 32 deg. F. without reheating. With dry air two expansions are all that can be got, whilst with reheated air it is possible to get five and six expansions, more so if the air is well saturated. Reheating with steam has been used with very good results, and, where found convenient, steam should be always used with air. Suppose a steam reheater was used for a pump within a reasonable distance from where a rock drill was being used, and the condensed steam was trapped, the trapped water would be led into a launder lying nearly level, so that the water would fill the launder. The air pipe leading to the drills is then immersed in the water, which would have a temperature of probably 140 deg. F. The air would have the same temperature as the water. Suppose it was only 100 deg. F. when delivered at the drills, it would always give a little help towards economy.

In the matter of economy, both in generating and in distributing compressed air, if proper care is exercised so that the machine is as nearly perfect as can be, the receivers and the pipe main perfectly free from leakage, with only one safety valve, no matter how many receivers there are on the distributing main, and that one safety valve fitted with a good strong siren that will make the attendant wish he had been more careful every time it blows off, the transmission of power by compressed air should be at the very least equal to any other method. Whilst compressed air has many disadvantages, it has also many advantages that other sources of energy have not got. For instance, in deep mining such as we will have in the Rand presently, when depths of 2,000 and 3,000 ft. will be quite common, and temperature of between 90 deg. and 100 deg. F. compressed air will gain where electricity would lose. First, the weight of air in the column will add to the pressure, not to a great extent, but probably quite enough to make up for what has been lost in friction; at a depth of 2,000 ft. with air at 80 lbs. pressure on the surface, there would be a pressure of something like 87½ lbs. in the mine. Then, again, supposing the temperature of the atmosphere was 60 deg., and the temperature of the mine was 96 deg., at 3,000 ft. the air would be reheated 36 deg. F., showing a gain of about 4 per cent., the mine itself acting as a reheater. Thus it will be seen that for deep mining, where high temperature may be expected, compressed air will increase in economy, whilst, as I have already endeavored to point out, other sources of energy would keep on losing and regain nothing. Although not yet in economy, yet in many other ways does compressed air appeal to the mechanical engineer; it is perfectly safe, accidents caused by compressed air are so very rare that they are practically unknown. Should an air pipe burst, no harm is done except the loss that is caused by leakage. As a proof of its growing popularity we have only to take up the advertisement columns of an engineering paper, and we find that the different appliances that are operated by compressed air are simply innumerable. We read about pneumatic painters, pneumatic cranes, and pneumatic so many differen things, that I could stand here for another hour doing nothing else but reading over a list of the different appliances that are operated by compressed air. In fact, it would seem that it is just beginning to dawn upon the engineering world that the greatest force in nature is the air we breathe when put into the proper form. And now that the first blush of electricity has worn off, and scientific men are looking for new fields of thought, I think I am safe in predicting that compressed air will come in for a considerable amount of attention, and great developments may be looked for during the next few years.

Driving Drift Pins with a New Device.

An interesting labor-saving appliance which we describe and illustrate on cover, has lately been put into practical use by Mr. D. E. Moran, M. E., of New York.

The contractors for the new water works for the City of Cincinnati had to build a caisson 130 ft. in diam. x 3 ft. thick. The platform of this caisson was made of timber and required about 70,000 drift pins 1 in. diam. x 30 in. long to make it rigid and to hold the timbers in position. Originally the work of driving the

drift pins was done by hand and it took a gang of three laborers, each paid $1.50 per day, to drive 200 drifts per day. The holes for the drifts were drilled with several "Phœnix" Pneumatic wood boring machines built by the C. H. Haeseler Co. of Philadelphia, one of which is shown in operation on right hand side of cut. The depth of these drift pin holes was 34" by $\frac{15}{16}$" diameter or in other words 4" longer and $\frac{1}{16}$" smaller than the pins themselves.

Mr. Moran, not satisfied with the progress of the work, conceived the idea of using an Ingersoll-Sergeant rock drill to dispense with the manual labor of hammering. He mounted a 3⅛ in. drill on a derrick, as shown on the illustration. The piston of the drill carried a hammer striking on an anvil, whose bottom was cupped and placed directly over the drift. By means of a double windlass the drill could either be raised or lowered and the total weight of the drill, with partial weight of the frame, would prevent any recoil when striking. The anvil being cupped at the bottom keeps the drill always central above the drift and by means of this appliance he was able to drive an average of 800 drifts per day with three men, while only 200 could be driven by hand, this being done at the same expense with the exception of compressed air power for running the drill. The cost of the power, however, was insignificant, as the company building the caisson have several large air compressors used for other purposes.

The frame supporting the drill being mounted on wheels, is easily moved from one drift pin hole to another, and we are informed that the total cost of the frame, with mountings above the original cost of the drill, did not exceed $75.00. Thus it will be seen that this simple method has not only saved the contractors about $2.00 per 100 drifts to be driven, but that it has increased the capacity, or, in other words, decreased the time of building the caisson some 75 per cent. We are also informed that the drill did better work than that done by hand labor, as the drifts driven mechanically were never bent, while by hand driving they were very often bent and tops bruised and required considerable labor and loss of time for straightening and final driving home.

Driving Pumps by Compressed Air.

By William Cox.

It is frequently desired to know in a simple manner how many cubic feet of free air at a certain pressure would be necessary to pump a given quantity of water to a required given height, without, for the time being, considering the sizes of the air and water cylinders or the piston speed. That this can be done, although not generally so supposed, and that by a very simple formula, will now be explained.

FIRST:—*Theoretically.*

Eq. (1) gives

$$G = 0{\cdot}0408 d^2 \times p_s$$

whence

$$d^2 = \frac{G}{0{\cdot}0408 p_s} \dots\dots\dots\dots\dots (11)$$

Eq. (7) stands

$$D_a{}^2 = \frac{0{\cdot}433 h \times d^2}{P} \dots\dots\dots\dots\dots (7)$$

Inserting the value of d^2 as given in Eq. (11) in Eq. (7) we have

$$D_a{}^2 = \frac{0{\cdot}433 h}{P} \times \frac{G}{0{\cdot}0408 p_s} \dots\dots\dots (12)$$

Again, we have by Eq. (9)

$$V = 0{\cdot}00545 D_a{}^2 \times p_s \times W_2 \dots\dots (9)$$

From equations (12) and (9) we obtain

$$V = 0{\cdot}00545 \frac{0{\cdot}433 h \times G}{P \times 0.0408 p_s} \times p_s \times W_2$$

and by canceling and reducing

$$V = 0{\cdot}05784 \frac{h \times G}{P} \times W_2 \dots\dots\dots (13)$$

the only quantities requiring to be known being

h = the head in feet to which the water is to be pumped,

G = the number of gallons of water to be pumped, and

P = the pressure of the air to be used.

SECOND:—With the various losses taken into account, as explained in the last article, Eq. (11) with 20 per cent. added gives

$$d^2 = \frac{120}{0{\cdot}0408 \times 100} \times \frac{G}{p_s}$$

$$= \frac{G}{0{\cdot}034 p_s} \dots\dots\dots\dots (14)$$

Eq. (7) with 15 per cent. added gives us

$$D_a^2=\frac{0{\cdot}5h\times d^2}{P}\ ..\text{same as}...(8)$$

Combining equations (14) and (8) we have

$$D_a^2=\frac{0{\cdot}5h}{P}\times\frac{G}{0{\cdot}034p_s}\cdots\cdots(15)$$

Again, equation (9) with 15 per cent. added gives us

$$V=0{\cdot}0063D_a^2\times p_s\times W_2\ \ldots(16)$$

and by combining equations (15) and (16) we obtain

$$V=0{\cdot}0063\frac{0{\cdot}5h\times G}{P\times 0{\cdot}034p_s}\times p_s\times W_2$$

and by canceling and reducing

$$V=0{\cdot}093\frac{h\times G}{P}\times W_2\ \ldots\ldots(17)$$

in which, as before, the only quantities required to be known are

h=the head in feet to which the water is to be pumped,

G=the number of gallons of water to be pumped, and

P=the pressure of the air to be used.

Let us now take the example given in detail in the last article, and see how nearly the results agree. We have given

h=80 feet,

G=100 gallons,

P=20 pounds, and

W_2 for P=20 pounds=2·36,

we have therefore by Eq. (17)

$$V=0{\cdot}093\frac{80\times 100}{20}\times 2{\cdot}36$$

$$=87{\cdot}8 \text{ cubic feet of free air}$$

as against 90 cubic feet found previously. The slight difference is however explained and fully covered by two or three items being taken in the former paper approximately, such for instance as the diameter of the water cylinder, which is 5·4 inches by the formula, and not 5·5 inches, which was taken from the table, which allows a slight over-volume of delivery (3·42 gallons).

The solution of the problem by this direct method therefore fully agrees with the step-by-step one, and for a preliminary study of any case which may arise, is very much simpler.

If it be found that such a quantity of free air is available, other details required for making the installation a success, can now be obtained by means of equations (14) and (8), which give in a very simple manner the diameters of the water and air cylinders, based upon any suitable piston speed.

Thus, by Eq. (14) and assuming a piston speed of 100 feet per minute, we have

$$d^2=\frac{G}{0{\cdot}034p_s}$$

$$=\frac{100}{0{\cdot}034\times 100}$$

$$=29{\cdot}41,\text{ and}$$

$$d=5{\cdot}4\text{ inches.}$$

Then by Eq (8) we have

$$D_a^2=\frac{0{\cdot}5h\times d^2}{P}$$

$$=\frac{0{\cdot}5\times 80\times 29{\cdot}41}{20}$$

$$=58{\cdot}82,\text{ and}$$

$$D_a=7{\cdot}67\text{ inches.}$$

It is the writer's opinion that equation (17) will be found exceedingly useful by mining and other engineers who may have to figure upon the use of compressed air for driving common pumps.

Another question which will also be of interest, although it may sometimes be overlooked, is the question of power cost. As previously stated, high powers are not, when examined from this stand-point, recommended.

The horse-power required by the air cylinder of a compressor is

$$H.P.=\frac{0{\cdot}7854d^2\times M_p\times p_s}{33000}\ \ldots(18)$$

and the volume of free air compressed by the same is

$$\frac{0.7854d^2\times p_s}{144}\ \ldots\ldots\ldots(19)$$

The horse-power required therefore by the air cylinder to compress one cubic foot of free air is found by dividing Eq. (18) by Eq. (19) which gives

$$P=\frac{0{\cdot}7854d^2\times M_p\times p_s\times 144}{0{\cdot}7854d^2\times p_s\times 33000}$$

$$=\frac{M_p}{229}\ \ldots\ldots\ldots\ldots\ldots\ldots(20)$$

The following table gives the mean effective resistance, or mean pressure M_p, to be overcome by the air cylinder piston to produce various terminal pressures, * and the horse-power required by the air cylinder to compress one cubic foot of free air to the same terminal pressures, calculated from Eq. (20).

TABLE II.

Terminal Pressure P	Mean Pressure P	Horse-power per cubic foot of free air.
20 pounds,	14.4 pounds,	0.0628
25 "	17.01 "	0.0743
30 "	19.4 "	0.0847
35 "	21.6 "	0.0943
40 "	23 66 "	0.1033
45 "	25.59 "	0.1117
50 "	27.39 "	0.1196

Referring again to Eq. (17) we may transpose it and obtain

$$h \times G = V \frac{P}{0{\cdot}093} W_2$$

and if we substitute for $\frac{P}{0{\cdot}093 W_2}$ the term X, we have

$$h \times G = V \times X \ldots\ldots\ldots\ldots\ldots (21)$$

The following table gives the values of W_2 and $0{\cdot}093\ W_2$ for different pressures, with the corresponding values of X.

TABLE III.

Pressure P	W_2	$0{\cdot}093 W_2$	$X = \frac{P}{0.093 W_2}$
5 pounds,	1.34	0.12462	40.122
10 "	1.68	0.15624	64.004
15 "	2.02	0.18786	79.846
20 "	2.36	0.21948	91.124
25 "	2.70	0.25110	99.562
30 "	3 04	0.28272	106.324
35 "	3.38	0.31434	111.344
40 "	3.72	0.34596	115.620
45 "	4.06	0.37758	119.180
50 "	4.40	0.40920	122.190

This table enables us to obtain in a very simple manner the volume of free air required to pump any given quantity of water to any desired height. Thus, to continue the example already referred to,

$$h \times G = 80 \times 100 = 8000,$$

and dividing by X or 91 (omitting decimals) we have for 20 pounds pressure

$$V = \frac{8000}{91} = 88 \text{ cubic feet of free air,}$$

which is practically identical with the solution already found by means of Eq. (17).

If we now combine Tables II and III, we obtain the following one, which will be often found useful:

TABLE IV.

$V \times X = h \times G$	P	V	H.P
9112	20 pounds,	100 cub. ft.	6.28
9956	25 "	" "	7.43
10632	30 "	" "	8.47
11134	35 "	" "	9.43
11562	40 "	" "	10.33
11918	45 "	" "	11.17
12219	50 "	" "	11.96

Taking the previous example, we have, therefore, for the horse-power required by the air cylinder

$$\frac{6{\cdot}28 \times 88}{100} = 5{\cdot}53 \text{ horse-power.}$$

It has been stated that high pressures are not economical. Let us, therefore, work out the foregoing example with an assumed pressure of 40 pounds, so as to be able to judge of the altered conditions.

We have therefore, in the first place, from Table III

$$\frac{h \times G}{X} = \frac{80 \times 100}{115{\cdot}6}$$

$$= 69 \text{ cubic feet of free air.}$$

Now, by Table IV we have

$$\frac{10{\cdot}33 \times 69}{100} = 7{\cdot}13 \text{ horse-power.}$$

We see therefore, that although there is an economy of 88–69=18 cubic feet of free air to be compressed, yet the power-cost of doing the work is 7·13–5·53=1·6 horse-power greater. Other cases, if similarly worked out, would demonstrate the same fact.

Formula (21) which is

$$h \times G = V \times X$$

shows

1st.—For a given pressure, the volume of free air required varies *directly* as h × G.

2nd.—If the product of head into quantity of water is the same in different cases, the pressure will vary *inversely* as the volume of free air required; or the volume of free air required will vary ***inversely*** as the pressure employed.

—* *From "Compressed Air," by Frank Richards, A. S. M. E.*

3rd.—For equal values of $\frac{h \times G}{V}$, the pressure necessary will be the same.

Thus if $V=100$, $h=100$ and $G=100$, then $X=100$, which is equivalent to a pressure of 25 pounds, as per table III.

So also, if $V=100$, $h=50$ and $G=200$, $X=$ also 100, and consequently as per same table the pressure required will likewise be 25 pounds.

I trust that it has been clearly shown that the volume of free air required and the power-cost can be ascertained without any reference to the sizes of the air and water cylinders, and that these are questions of detail to be afterwards considered in accordance with the formulas given, when working out plans for an installation.

Of course, the losses I have taken may vary from those stated, as much depends upon the pumps employed and the care used throughout in making the installation. The same method of treatment must, however, be followed in all cases.

In connection with what I have already written, it may be desirable sometimes to ascertain in a ready manner the ratio which should exist between the air and water cylinders so that the best results may be obtained. Equation (8) supplies this information in the simplest form. It is

$$D_a^2 = \frac{0.5h \times d^2}{P}$$

from which we obtain by transposition

$$D_a^2 : d^2 = 0.5h : P \quad \text{.........(22)}$$

or, to express it so that it may be easily memorized,

Area of air cylinder is to area of water cylinder as half the head is to the pressure.

or again, we have

$$D_a : d = \sqrt{0.5h} : \sqrt{P} \quad \text{........(23)}$$

that is,

Diameter of the air cylinder is to the diameter of the water cylinder, as square root of half the head is to square root of the pressure.

Taking the example already given, where $h=80$ feet, and $P=20$ pounds, we have

$$D_a^2 : d^2 = 40:20$$
$$= 2:1$$

or

$$D_a : d = \sqrt{2} : \sqrt{1}$$
$$= 1.414:1$$

It will be clear from what has been written in the first article that the FIRST point in every case to be carefully ascertained is the diameter of the water cylinder and the piston-speed, *after which* the required diameter of the air cylinder can be easily found by means of the above ratio-formula.

The diameter of the water cylinder depends upon the quantity of water to be pumped per minute and the piston-speed; or, in other words, the volumetric capacity of the water cylinder per minute is the sectional area of the cylinder multiplied by the length of stroke in inches, and the number of single strokes per minute. This product, which is the capacity in cubic inches, divided by 231, gives the capacity in U. S. gallons per minute. Reduced to its simplest form, this becomes as in Eq. (4)

$$d = 5.4 \sqrt{\frac{G}{p_s}}$$

In the above example we assumed $G=100$ and $p_s=100$ feet per minute, so we have

$$d = 5.4 \sqrt{\frac{100}{100}}$$
$$= 5.4 \text{ inches}$$

Given then, $d=5.4$ inches, clearly

$$D_a = \frac{d \times \sqrt{2}}{\sqrt{1}}$$

$$\text{or } D_a = 5.4 \times 1.414$$
$$= 7.64 \text{ inches,}$$

which agrees with the result already obtained, if in place of $D_a=5.5$ as previously given, we take $D_a=5.4$ inches as above. It should be remembered that the diameter 5.5 inches was taken from table I, and is correct for 102 gallons, but a little too much for 100 gallons. Of course, cylinders are not made to decimal sizes, such as 5.4 inches, but to fractional diameters as 5½ inches.

The following table gives the *ratio* of the diameter of the air cylinder to the diameter of the water cylinder for different heights to which the water is to be pumped, and for different air-pressures, the diameter of the water cylinder being taken throughout as 1 inch:

TABLE V.

Ratios of diameter of air cylinder to diameter of water cylinder.

Height, Feet	Pressures						
	20 LBS.	25 LBS.	30 LBS.	35 LBS.	40 LBS.	45 LBS.	50 LBS.
50	1.12	1.00	0.91	0.84	0.79	0.74	0.71
100	1.58	1.41	1.29	1.20	1.12	1.05	1.00
125	1.77	1.58	1.45	1.34	1.25	1.18	1.12
150	1.94	1.73	1.58	1.45	1 37	1.29	1.22
175	2.09	1.87	1.70	1.58	1.48	1.39	1.32
200	2.24	2.00	1.82	1.69	1.58	1.49	1.41
225	2.37	2.12	1.94	1.79	1.68	1.58	1.50
250	2.50	2.24	2.05	1.90	1.77	1.67	1.58
275	2.62	2.35	2.14	1.98	1.85	1.75	1.66
300	2.74	2.45	2.24	2.07	1.94	1.82	1.73
325	2.85	2.55	2.33	2.16	2.02	1.90	1.80
350	2.96	2.64	2.42	2.24	2.09	1.97	1.87
375	3.06	2.74	2.50	2.31	2.16	2.04	1.94
400	3.16	2.83	2.58	2.39	2 23	2.11	2.00
425	3.26	2.92	2.66	2.46	2.30	2.17	2.06
450	3.35	3.00	2.74	2.53	2.37	2.24	2.12
475	3.44	3.08	2.82	2.60	2.44	2.30	2.18
500	3.53	3.16	2.89	2.67	2.50	2.36	2.24

Ratios for intermediate heights and pressures may be obtained by interpolation.

Example. 200 gallons of water to be pumped to a height of 125 feet, the air-pressure being 25 pounds. Piston-speed 100 feet per minute.

We have in the first place

$$\text{Diameter water cylinder} = 5{\cdot}4\sqrt{\frac{200}{100}}$$

$$= 5{\cdot}4 \times \sqrt{2} = 7{\cdot}64 \text{ inches.}$$

Now, by table V, we find under 25 pounds pressure, in line with 125 feet height, the ratio 1·58 to 1, so that the diameter of the air cylinder should be

$$7{\cdot}64 \times 1{\cdot}58 = 12{\cdot}1 \text{ inches.}$$

In practice these two sizes will of course not be met with, so to secure the pumping of the required quantity of water we may safely select a pump with an 8-inch water cylinder. Then, according to the ratio of 1·58 to 1·0, we should have an air cylinder of 8 × 1·58 = 12·64 inches diameter. If a 13-inch cylinder could be had, it would about fill the requirements; but as such a combination is hardly likely to be met with, we should probably have to take a 12 inch, and try to force the air-pressure up to 28 pounds, which is about the interpolated value by the table for a ratio of 1·50 to 1·0, or 12 to 8 inches.

By following as near as can be the ratios set forth in table V, and slightly adjusting piston-speed and air-pressure so as to counterbalance any slight variation of diameters of the cylinders, water may be pumped in any quantity to any height, with the least volume of free-air possible, in accordance with Eq. (17). Common pumps may then do their work economically (relatively), and compressed-air will be looked upon as a valuable and not a wasteful agent. To repeat an old saying, *Use, but do not abuse.* Of course, if the pumps are of the best, and in good condition, the various losses may be slightly reduced, and somewhat more favorable results may be obtained.

Example. It is required to raise 200 gallons of water per minute to a height of 125 feet, the maximum air-pressure being 30 pounds.

The quantity of water being considerable, and requiring necessarily a fair sized cylinder, let us assume a piston-speed of 120 feet per minute.

We have in the first place by Eq. (4)

$$d = 5{\cdot}4\sqrt{\frac{G}{p_s}}$$

$$= 5{\cdot}4\sqrt{\frac{200}{120}} = 6{\cdot}97 \text{ inches.}$$

Now, by table V, we see that for 30 pounds pressure and a height of 125 feet, the ratio of the cylinders is 1·45 to 1·0, which gives for the air cylinder 10·1 inches, or say 10 inches for the air cylinder and 7 inches for the water cylinder.

We then have for the volume of free-air required, by Eq. (10)

$$V = 0{\cdot}0063 D_a^2 \times p_s \times W_2$$

$$= 0{\cdot}0063 \times 100 \times 120 \times 3{\cdot}04$$

$$= 229{\cdot}8 \text{ cubic feet.}$$

To verify this result, and to see how near it approaches the ideal, we have by Eq. (17)

$$V = 0{\cdot}093\frac{h \times G}{P} \times W_2$$

$$= 0{\cdot}093\frac{125 \times 200}{30} \times 3{\cdot}04$$

$$= 235 \text{ cubic feet.}$$

Allowing for the decimals in the different equations, we see that the results obtained by the two methods substantially agree. We may, therefore, say that for the case under consideration a better combination could scarcely be had than that found as above, namely 10 by 7 inch cylinders, 30 pounds air-pressure, and 120 feet piston-speed.

Driving Pumps by Compressed Air. *

Table:- giving the volume of free air, at pressures of 20 to 50 pounds, required to pump any given quantity of water to any height, with the corresponding horse-power required by the air-cylinder to do the work

Compiled by William Cox.

h × G	P = 20 lbs		P = 25 lbs		P = 30 lbs		P = 35 lbs		P = 40 lbs		P = 45 lbs		P = 50 lbs		h × G
	V	H-P	V	H-P	V	H-P	V	H-P	V	H-P	V	H-P	V	H-P	
500	5.66	0.39	5.18	0.42	4.86	0.45	4.64	0.48	4.46	0.50	4.33	0.53	4.22	0.56	500
1000	11.32	0.78	10.36	0.84	9.72	0.90	9.28	0.96	8.92	1.01	8.66	1.06	8.44	1.12	1000
1500	16.98	1.17	15.54	1.26	14.58	1.35	13.92	1.44	13.38	1.51	12.99	1.59	12.66	1.68	1500
2000	22.64	1.56	20.72	1.68	19.44	1.80	18.56	1.92	17.84	2.02	17.32	2.12	16.88	2.24	2000
2500	28.30	1.95	25.90	2.10	24.30	2.25	23.20	2.40	22.30	2.52	21.65	2.65	21.10	2.80	2500
3000	33.96	2.34	31.08	2.52	29.16	2.70	27.84	2.88	26.76	3.03	25.98	3.18	25.32	3.36	3000
3500	39.62	2.73	36.26	2.94	34.02	3.15	32.48	3.36	31.22	3.53	30.31	3.71	29.54	3.92	3500
4000	45.28	3.12	41.44	3.36	38.88	3.60	37.12	3.84	35.68	4.04	34.64	4.24	33.76	4.48	4000
4500	50.94	3.51	46.62	3.78	43.74	4.05	41.76	4.32	40.14	4.54	38.97	4.77	37.98	5.04	4500
5000	56.60	3.90	51.80	4.20	48.60	4.50	46.40	4.80	44.60	5.05	43.30	5.30	42.20	5.60	5000
5500	62.26	4.29	56.98	4.62	53.46	4.95	51.04	5.28	49.06	5.55	47.63	5.83	46.42	6.16	5500
6000	67.92	4.68	62.16	5.04	58.32	5.40	55.68	5.76	53.52	6.06	51.96	6.36	50.64	6.72	6000
6500	73.58	5.07	67.34	5.46	63.18	5.85	60.32	6.24	57.98	6.56	56.29	6.89	54.86	7.28	6500
7000	79.24	5.46	72.52	5.88	68.04	6.30	64.96	6.72	62.44	7.07	60.62	7.42	59.08	7.84	7000
7500	84.90	5.85	77.70	6.30	72.90	6.75	69.60	7.20	66.90	7.57	64.95	7.95	63.30	8.40	7500
8000	90.56	6.24	82.88	6.72	77.76	7.20	74.24	7.68	71.36	8.08	69.28	8.48	67.52	8.96	8000
8500	96.22	6.63	88.06	7.14	82.62	7.65	78.88	8.16	75.82	8.58	73.61	9.01	71.74	9.52	8500
8834	100.–	6.89	91.52	7.42	85.86	7.95	81.98	8.48	78.80	8.92	76.50	9.36	74.55	9.90	8834
9000	101.88	7.02	93.24	7.56	87.48	8.10	83.52	8.64	80.28	9.09	77.94	9.54	75.96	10.08	9000
9500	107.54	7.41	98.42	7.98	92.34	8.55	88.16	9.12	84.74	9.59	82.27	10.07	80.18	10.64	9500
9.652	109.26	7.53	100.–	8.13	93.82	8.69	89.58	9.27	86.10	9.75	83.59	10.23	81.46	10.81	9.652
10000	113.20	7.80	103.60	8.40	97.20	9.00	92.80	9.60	89.20	10.10	86.60	10.60	84.40	11.20	10000
10288	116.26	8.02	106.58	8.64	100.–	9.25	95.47	9.88	91.77	10.39	89.09	10.91	86.83	11.52	10288
10776	121.98	8.40	111.21	9.05	104.74	9.70	100.–	10.34	96.12	10.88	93.32	11.42	90.95	12.07	10776
11218	126.99	8.75	116.14	9.42	108.97	10.10	104.04	10.77	100.–	11.32	97.09	11.89	94.62	12.56	11218
11547	130.71	9.01	119.63	9.70	112.24	10.39	107.16	11.09	103.00	11.66	100.–	12.24	97.46	12.93	11547
11847	134.11	9.24	122.75	9.95	115.17	10.66	109.95	11.37	105.69	11.96	102.61	12.56	100.–	13.27	11847
12500	141.50	9.75	129.50	10.5	121.50	11.25	116.00	12.0	111.50	12.62	108.25	13.25	105.50	14.0	12500
15000	169.8	11.70	155.4	12.6	145.8	13.50	139.2	14.4	133.8	15.15	129.90	15.90	126.6	16.8	15000
17500	198.1	13.65	181.3	14.7	170.1	15.75	162.4	16.8	156.1	17.68	151.55	18.55	147.7	19.6	17500
20000	226.4	15.60	207.2	16.8	194.4	18.00	185.6	19.2	178.4	20.20	173.20	21.20	168.8	22.4	20000
22500	254.7	17.55	233.1	18.9	218.7	20.25	208.8	21.6	200.7	22.72	194.85	23.85	189.9	25.2	22500
25000	283.0	19.50	259.0	21.0	243.0	22.50	232.0	24.0	223.0	25.25	216.50	26.50	211.0	28.0	25000
27500	311.3	21.45	284.9	23.1	267.3	24.75	255.2	26.4	245.3	27.78	238.15	29.15	232.1	30.8	27500
30000	339.6	23.40	310.8	25.2	291.6	27.00	278.4	28.8	267.6	30.30	259.80	31.80	253.2	33.6	30000
32500	367.9	25.35	336.7	27.3	315.9	29.25	301.6	31.2	289.9	32.82	281.45	34.45	274.3	36.4	32500
35000	396.2	27.30	362.6	29.4	340.2	31.50	324.8	33.6	312.2	35.35	303.10	37.10	295.4	39.2	35000
37500	424.5	29.25	388.5	31.5	364.5	33.75	348.0	36.0	334.5	37.88	324.75	39.75	316.5	42.0	37500
40000	452.8	31.20	414.4	33.6	388.8	36.00	371.2	38.4	356.8	40.40	346.40	42.40	337.6	44.8	40000
42500	481.1	33.15	440.3	35.7	413.1	38.25	394.4	40.8	379.1	42.92	368.05	45.05	358.7	47.6	42500
45000	509.4	35.10	466.2	37.8	437.4	40.50	417.6	43.2	401.4	45.45	389.70	47.70	379.8	50.4	45000
47500	537.7	37.05	492.1	39.9	461.7	42.75	440.8	45.6	423.7	47.98	411.35	50.35	400.9	53.2	47500
50000	566.0	39.00	518.0	42.0	486.0	45.00	464.0	48.0	446.0	50.50	433.00	53.00	422.0	56.0	50000
52500	594.3	40.95	543.9	44.1	510.3	47.25	487.2	50.4	468.3	53.02	454.65	55.65	443.1	58.8	52500
55000	622.6	42.90	569.8	46.2	534.6	49.50	510.4	52.8	490.6	55.55	476.30	58.30	464.2	61.6	55000
57500	650.9	44.85	595.7	48.3	558.9	51.75	533.6	55.2	512.9	58.08	497.95	60.95	485.3	64.4	57500
60000	679.2	46.80	621.6	50.4	583.2	54.00	556.8	57.6	535.2	60.60	519.60	63.60	506.4	67.2	60000
62500	707.5	48.75	647.5	52.5	607.5	56.25	580.0	60.0	557.5	63.12	541.25	66.25	527.5	70.0	62500

Driving Pumps by Compressed Air. —(Continued.)

Table:— giving the volume of free air, at pressures of 20 to 50 pounds, required to pump any given quantity of water to any height, with the corresponding horse-power required by the air-cylinder to do the work. *Compiled by William Cox.*

h×G	P = 20 lbs		P = 25 lbs		P = 30 lbs		P = 35 lbs		P = 40 lbs		P = 45 lbs		P = 50 lbs		h×G
	V	H-P	V	H-P	V	H-P	V	H-P	V	H-P	V	H-P	V	H-P	
65000	735.8	50.70	673.4	54.6	631.8	58.50	603.2	62.4	579.8	65.65	562.9	68.90	548.6	72.8	65000
67500	764.1	52.65	699.3	56.7	656.1	60.75	626.4	64.8	602.1	68.18	584.5	71.55	569.7	75.6	67500
70000	792.4	54.60	725.2	58.8	680.4	63.00	649.6	67.2	624.4	70.70	606.2	74.20	590.8	78.4	70000
72500	820.7	56.55	751.1	60.9	704.7	65.25	672.8	69.6	646.7	73.22	627.8	76.85	611.9	81.2	72500
75000	849.0	58.50	777.0	63.0	729.0	67.50	696.0	72.0	669.0	75.75	649.5	79.50	633.0	84.0	75000
77500	877.3	60.45	802.9	65.1	753.3	69.75	719.2	74.4	691.3	78.28	671.1	82.15	654.1	86.8	77500
80000	905.6	62.40	828.8	67.2	777.6	72.00	742.4	76.8	713.6	80.80	692.8	84.80	675.2	89.6	80000
82500	933.9	64.35	854.7	69.3	801.9	74.25	765.6	79.2	735.9	83.32	714.4	87.45	696.3	92.4	82500
85000	962.2	66.30	880.6	71.4	826.2	76.50	788.8	81.6	758.2	85.85	736.1	90.10	717.4	95.2	85000
87500	990.5	68.25	906.5	73.5	850.5	78.75	812.0	84.0	780.5	88.38	757.7	92.75	738.5	98.0	87500
90000	1018.8	70.20	932.4	75.6	874.8	81.00	835.2	86.4	802.8	90.90	779.4	95.40	759.6	100.8	90000
92500	1047.1	72.15	958.3	77.7	899.1	83.25	858.4	88.8	825.1	93.42	801.0	98.05	780.7	103.6	92500
95000	1075.4	74.10	984.2	79.8	923.4	85.50	881.6	91.2	847.4	95.95	822.7	100.70	801.8	106.4	95000
97500	1103.7	76.05	1010.1	81.9	947.7	87.75	904.8	93.6	869.7	98.48	844.3	103.35	822.9	109.2	97500
100000	1132.0	78.00	1036.0	84.0	972.0	90.00	928.0	96.0	892.0	101.0	866.0	106.00	844.0	112.0	100000
125000	1415	97.5	1295.0	105.0	1215	112.5	1160.0	120.0	1115	126.2	1082.5	132.5	1055	140.0	125000
150000	1698	117.0	1554	126.0	1458	135.0	1392	144.0	1338	151.5	1299.0	159.0	1266	168.0	150000
175000	1981	136.5	1813	147.0	1701	157.5	1624	168.0	1561	176.8	1515.5	185.5	1477	196.0	175000
200000	2264	156.0	2072	168.0	1944	180.0	1856	192.0	1784	202.0	1732.0	212.0	1688	224.0	200000

Directions.— Multiply the gallons of water to be raised per minute by the height in feet to which the water is to be raised. Opposite this product in the first and last columns, headed h×G, find under the different pressures the cubic feet of free air per minute and the horse-power required. Intermediate values of h×G give directly proportionate results for the various pressures at the head of the different columns.

Note:— h = height in feet to which the water is to be raised. G = gallons of water to be pumped per minute. V = cubic feet free air required per minute. H-P = horse-power.

Improvements in Pneumatic Caissons, Air Locks and Shafts.

Within the past two years Mr. John F. O'Rourke has made a number of important improvements in sinking pneumatic caissons, the main objects in the inventions relating principally to the method of swinging the gates in the air lock and to certain safety devices. To be more specific, his improvements relate to both the caisson shaft and the air lock. In the former of these means were provided in the side wall of the shaft for a series of transverse slots, arranged one above another, as seen in Fig. 2, forming a ladder, thereby affording a means of obtaining access to the air chamber, independent of the bucket, and also providing a means of escape if necessary. Inasmuch as the buckets or cages must be left free to move up and down, it is necessary to provide an unobstructed interior and leave the walls practically plain, so that nothing can interfere with the movement of the bucket and thereby cause damage or accident. It will be noted, therefore, that this part of the invention is principally for the purpose of providing a shaft with a ready means of ascent or descent for the workmen. An air seal for the slots, whereby the escape of air from the shaft is prevented, is also included in the invention.

The improvements in the air locks are intended to provide a comparatively simple lock, with gates at the upper and lower ends, which make air tight closures, and also work quickly and with certainty. The most important modification in the recent designs lies in the method of

hanging the doors, so as to cause their ready separation by means of a lever and counterbalance, as shown in the accompanying illustrations.

The side elevation, Fig. 2, shows the air lock at the top, below which is the elevator or air shaft, with the ladder, as shown, and at the extreme lower part is the air chamber. The openings, M and

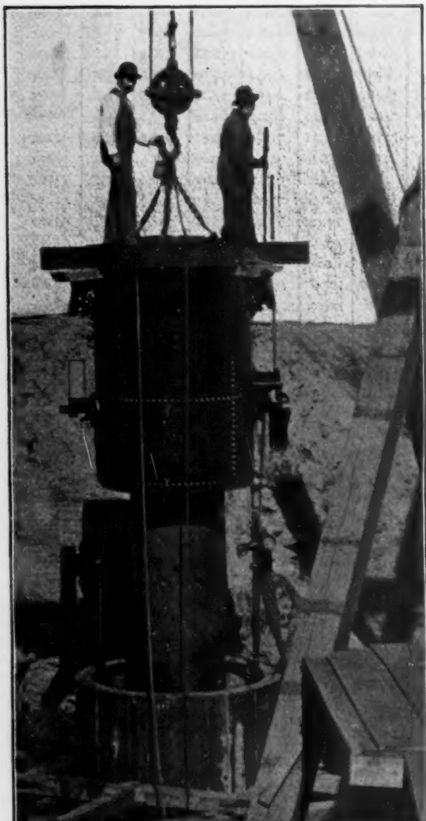

FIG. 1.—O'ROURKE'S AIR LOCK AND CAISSON IN POSITION.

N, are, respectively, for the air pipe and the whistle connection, as shown in the engraving, Fig. 1. The other illustrations give the details of the internal arrangement. The different views are so lettered that a reference to any part on one corresponds equally well to the same apparatus, as designated by the same letter in all of the views.

Referring to Figs. 3 and 4, the upper swinging gates, A and A^1, turn about the center, O, being counterweighted by V and W. These are worked by the handle, L, both gates swinging on the centers D and H.

When the upper gates have been moved to the open position, so as to come at rest on the lugs, B and B^1, the buckets can be moved in or out of the air chamber. The meeting edges of these, as well as the lower gates, are packed with rubber tongues, so as to make air-tight closures. The lower swinging gates are worked in the same manner, being opened and closed by the lever L^1, and counterweighted by W^1 V^1.

The successive operations are as follows: The bucket is lowered into the air lock, the upper gates being open and the lower ones closed. The upper ones are then closed and air is admitted from the air shaft until the pressure equals the pressure in the air chamber. The lower gates are then opened and the bucket descends into the shaft and finally into the air chamber.

Fig. 5 is a part sectional view showing the roof of the caisson, the levers, counterweight and other devices. Q is a three-way valve, which serves three purposes: First, it permits air to escape from the air lock; second, it equalizes the pressures in the air chamber and the air lock, and, third, prevents the escape of air from either. It is regulated by means of the contact wheels Y and Z, which in turn are moved by connecting with the handle L by means of a rod not shown in the drawings. When the upper gates are closed the motion of the lever simultaneously closes the air exhaust from the air lock and makes connection with the air chamber below, thus equalizing the pressure in the two chambers. A thumb latch locks these doors in both the open and in the closed positions. The arrangement of the lower swinging gates prevents their movement until the pressures in the upper and lower chambers have been equalized. Air is exhausted from the air lock by a 3-in. pipe, using the same valve shown in Fig. 4.

The air lock is 5 ft. in diameter by 7 ft. in height. The diameter of the caissons

used for the dwelling referred to was 6 ft. 7½ in., which is one of the smallest sizes that has yet been built under such difficult conditions, where so much blasting and rock excavation was required.

One of the most important improvements in the construction of the caisson is in the use of wood instead of steel for the outside shell. The lower sectional view, Fig. 2, gives a general notion of the way that the caisson is made. Yellow pine sticks 3½ in. in thickness, about 6 in. in width and 9 to 11 ft. long, are carefully put together, as shown in the drawing. This construction is as strong as the steel caisson, and is more durable. The wood is painted and then given a coating of tar before it is put in place. The engraving, Fig. 1, shows the first section of the caisson being put in place. It is weighted by means of pig iron, the weight resting on the roof, and as the cofferdam sinks it is necessary to keep adding weight until as much as 50 tons may be required. As the caisson descends the air lock is removed and sections are added to the air shaft, keeping the air lock above ground at all times. The wood construction for the caissons in place of the steel usually employed makes it possible to tell with certainty about how long it will take to make the foundations. Where steel is used the contractor may be delayed for months before he can have his order filled at the rolling mills. The cost also of the wooden caisson is somewhat less, but the great importance lies in the saving of time.

The pressure is very low at the beginning of the work, but is gradually increased as required, a sufficient amount being kept in the lower chamber to keep out the water.

These caissons, as improved, have recently been successfully used in making the foundations which have just been completed at No. 11 East Sixty-second Street, New York City, and the engraving, Fig. 1, gives a general idea of the method of working at that place. The foundations referred to have been made for the dwelling of Mrs. Elliot F. Shepard, and this is the only private house for which pneumatic caissons have been used. Before the solid rock was reached the caissons were forced through rock fill, then mud and clay, and finally through hard pan and boulders.

The architects of this building are Messrs. Haydel & Shepard, of New York. The consulting engineer is Mr. George

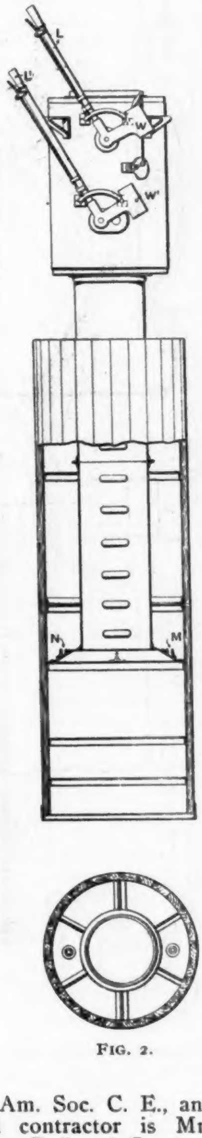

FIG. 2.

Hill, M. Am. Soc. C. E., and the engineer and contractor is Mr. John F. O'Rourke.—Railroad Gazette.

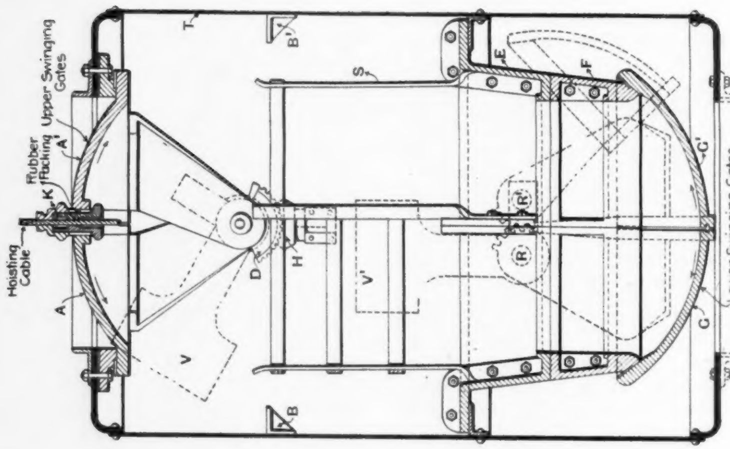

FIG. 3.—SECTION OF AIR LOCK.

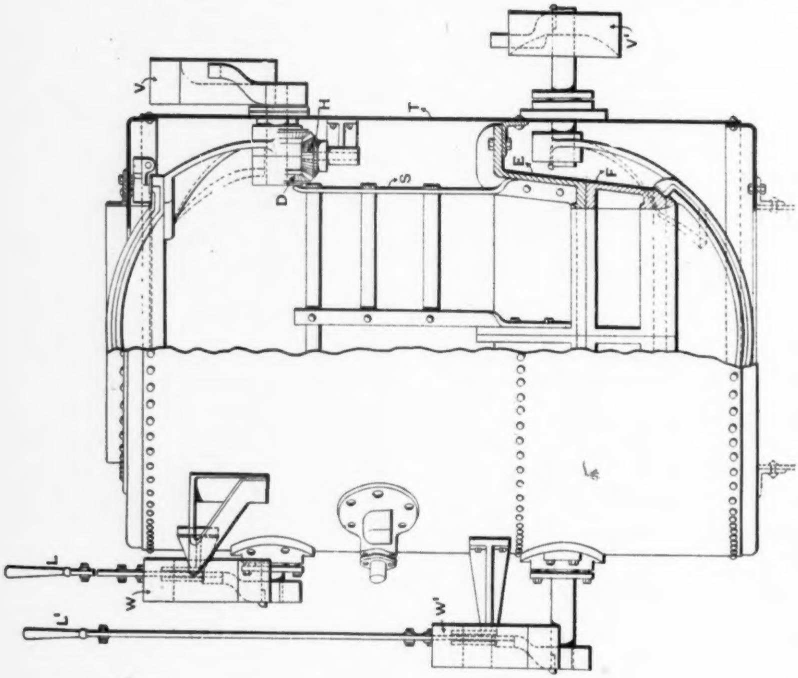

FIG. 4.—AIR LOCK—VIEW AT RIGHT ANGLES TO FIG. 3.

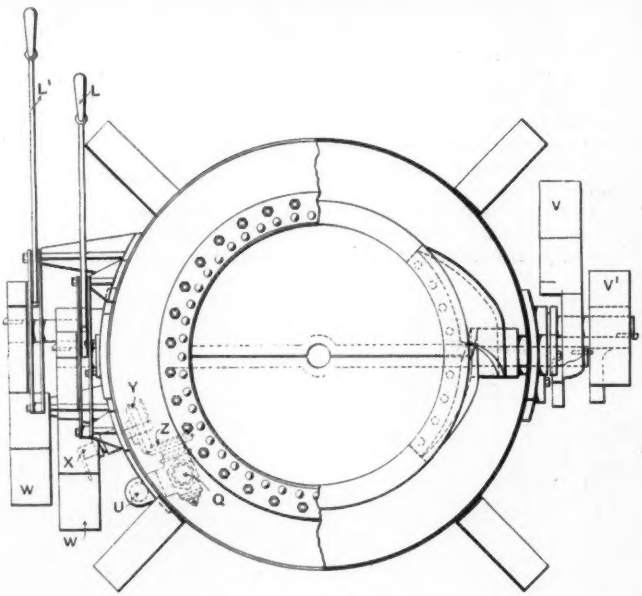

FIG. 5.—TOP VIEW AND SECTION.

Compressed Air Riveting Plant.

An interesting application of the use of compressed air may be seen a short distance out from the Erie Railroad depot at Jersey City. The Erie Railroad is elevating its tracks through the city, and at every street crossing there is an iron bridge. The work of riveting these bridges until recently has been done by hand, with the usual results that a gang of two men and two boys will drive on an average of 300 rivets a day of ten hours. The rivets to be driven are five-eighths inch and seven-eighths inch diameter.

A compressed air riveting plant has now been substituted for the hand riveters with the result that one man and three boys are driving 1,200 five-eighths inch and 1,000 seven-eighths inch rivets a day, with less effort and in a much more satisfactory manner.

The plant has now been in operation about one month, and so far has proved to be reliable and entirely satisfactory. It consists of a Fairbanks-Morse direct connected gasoline engine air compressor of 12 B.H.P., capable of delivering 70 cu. ft. of free air at 80 lbs. pressure per minute. The compressor is mounted in a box car, together with the water-cooling tank, fuel supply and air receiver. The car is drawn up on a side track near the work and the hose carried up on the structure. This arrangement is clearly shown in engraving. The car will be seen at the left in the cut, while the men at work with the pneumatic riveters are in the foreground.

The compressor is fitted with an automatic unloading device which opens the air cylinder exhaust to the atmosphere when the receiver has reached the required pressure; the engine governor then acts and cuts down the fuel supply, the speed of the engine remaining constant.

The pneumatic riveters used are those of the Chicago Pneumatic Tool Co. They are somewhat larger than the usual hammers

and are designed to set up seven-eighths and one-inch rivets. The air used in one of these hammers is 25 cu. ft. per minute.

There is also at work a Chicago piston pneumatic drill with which the holes are reamed out true before the rivet is inserted. This drill works very rapidly, and one man readily replaces four men using the old drift pin method of aligning holes.

It will be seen from the foregoing that the seventy-foot compressor plant here used will handle two of the large riveters and one drill.

RIVETING ON BRIDGE ERIE R. R. ELEVATION. POWER OBTAINED FROM GASOLINE AIR COMPRESSOR IN BOX CAR TO THE LEFT.

The fuel cost of delivering 70 feet of free air per minute at 80 lbs is approximately 12 cents per hour. The gasoline used is what is known as 74° common stove gasoline.

Catalogues and Circulars.

The Merrill Pneumatic Pump Company of 141 Broadway, New York, have issued an Advance Circular showing in detail the construction and operation of the Merrill Pneumatic Pump, It is a displacement pump, utilizing compressed air from any convenient source of generation, for elevating moderate and large quantities of water. The circular is well printed and contains excellent engravings showing the various methods of pumping by this system.

H. K. Porter & Co. have sent us a copy of catalogue showing "Light Locomotives." In it is illustrated compressed air locomotives, designed for use in mines, street railways and for other purposes. This company has made important advances in this line of compressed air work, and the catalogue is a valuable one for those who have need of it.

The Argonaut is the title of a handsome pamphlet issued by the Lake Submarine Co., New York. It is the description and illustration of the submarine boat bearing that name. This boat is designed not only for warfare, but has practical commercial uses, such as wrecking sunken vessels, submarine exploration, laying submarine foundations for piers, docks, breakwaters, etc. In operation it is similar to the Holland boat, using compressed air for various purposes, indispensable to her existence.

The Q. & C. Co., Chicago and New York, have provided us with a catalogue showing the valveless pneumatic tools manufactured and sold by them.

We have inquiries for the March, 1897, number of "COMPRESSED AIR." If any of our readers have one or more copies to spare we will remit ten cents for each copy.

ALPHABETICAL LIST OF PNEUMATIC INVENTIONS.

For which United States patents have been granted. Prepared for COMPRESSED AIR from official records by GRAFTON L. McGILL.

APPLIANCE.	NAME OF INVENTOR.	DATE OF ISSUE.	NO.
Air Brakes	James	July 6, 1875	165,235
"	"	Feb. 24, 1891	447,236
"	"	Oct. 13, 1891	461,243
"	"	August 21, 1894	524,990
"	Jeffries	Jan. 23, 1894	513,267
"	"	Nov. 26, 1895	550,346
"	Jones	August 3, 1875	166,386
"	Juul	Nov. 3, 1896	570,483
"	Keywood	July 4, 1893	500,910
"	Knapp	June 4, 1878	204,440
"	Kneeland	Oct. 26, 1886	351,383
"	Knudsen	Feb. 9, 1892	468,387
"	"	Sept. 4, 1894	525,686
"	Kholodkowski	March 15, 1898	600,537
"	Ladd	July 6, 1875	165,337
"	Lansberg	July 24, 1888	386,640
"	"	Nov. 13, 1888	392,872
"	"	Nov. 19, 1889	415,513
"	Lansberg	Nov. 19, 1889	415,514
"	"	Nov. 19, 1889	415,515
"	"	Nov. 19, 1889	415,516
"	"	Nov. 19, 1889	415,517
"	Lansberg	Oct. 28, 1890	439,528
"	"	Feb. 3, 1891	445,899
"	"	March 20, 1894	516,936
"	Lapish	March 12, 1889	399,420
"	Lee	March 31, 1896	557,511
"	"	March 31, 1896	557,512
"	"	March 31, 1896	557,513
"	"	March 31, 1896	557,514
"	"	March 31, 1896	557,515
"	Lehy	April 17, 1888	381,392
"	Lencke	April 10, 1894	517,955
"	" et al	April 10, 1894	517,954
"	Lewis	Sept. 3, 1889	410,288
"	Lewis	May 29, 1888	383,819
"	Lindsey	June 9, 1896	561,596
"	Lorraine	August 23, 1881	246,166
"	Loughridge	Nov. 9, 1880	234,134
"	Luce	Sept. 10, 1872	131,286
"	McAvoy	April 29, 1873	138,339
"	McCarty	Nov. 13, 1894	529,290
"	McIntosh	August 31, 1897	589,265
"	McKinney	Jan. 27, 1885	311,190
"	McNulta	March 29, 1892	471,801
"	Mable	Sept. 18, 1894	526,189
"	Mable	Dec. 8, 1896	572,553
"	Magowan	Feb. 12, 1884	293,481
"	Maher	August 5, 1890	433,737
"	Marble	Oct. 11, 1892	484,034
"	Mark	Nov. 4, 1884	307,561
"	Marsh	Jan. 15, 1889	396,284
"	Marshall	May 26, 1896	560,730

ALPHABETICAL LIST OF PNEUMATIC INVENTIONS.—*Cont.*

APPLIANCE.	NAME OF INVENTOR.	DATE OF ISSUE.	NO.
Air Brake	Marshall	July 21, 1891	456,199
"	Martin	Sept. 30, 1890	437,218
"	Massey	April 28, 1891	451,409
"	"	March 10, 1891	447,783
"	Massey	March 19, 1895	535,844
"	"	April 9, 1895	537,057
"	Massey	July 4, 1893	501,016
"	Massey	Nov. 12, 1889	414,717
"	Masterman	August 29, 1893	504,227
"	Maxwell	June 25, 1889	405,968
"	Maxwell	August 20, 1878	207,126
"	Melson	Nov. 23, 1886	352 927
"	Mills	April 16, 1894	537,784
"	Mills	June 7, 1892	476,546
"	Moschcowitz	August 27, 1875	166,026

PATENTS GRANTED DEC., 1898.

Specially prepared for COMPRESSED AIR from the Patent Office files by Grafton L. McGill, Washington. D. C.

615,326.—Air Brake. J. F. Voorhees, Philadelphia, Pa.

This invention embraces a continuous automatic brake, its object being to enable energy to be stored at each car to apply the brakes with an amount of force proportionate to the resistance to their action, without such stored energy exceeding a specific amount, unless determined by the engineer, and then only in such quantities as will prevent the wheels from sliding. The quick-acting relief valve is connected directly to the brake cyclinder, spring-valved mechanism being provided whereby the engineer may regulate the maximum load of the relief valve.

615,440.—Pneumatic Dry Dock. C. N. Dutton, New York, N. Y.

A movable docking member has a downwardly-decreasing open-bottomed air chamber. A working deck, adapted to receive a vessel and its supports, has its air chamber connected by valve-controlled air conduits to the open-bottomed air chamber of a movable balance member. Parallel racks are arranged on the docking member and upon fixed supports, while synchronizing shafts carry pinions meshing with the parallel racks. On the adjacent ends of the sections of the shafts are couplings, whereby the sections of the docking members may be operated either independently for docking two small vessels or as a unit for docking a large vessel.

615,668.—Alternating Air Pressure System. W. H. Barr, Wichita, Kansas.

A cylinder, having a central partition therein, is provided with lugs on its sides. Supporting rods are passed through the lugs, whereby the cylinder is adapted to reciprocate upon them. An air pipe enters each end of the cylinder, means being provided for alternately supplying air thereto, while a driving arm is secured to the cylinder for transmitting power.

615,717.—Pneumatic Gas Lighter. Ewald Knapp, Assignor, Cologne, Germany.

This invention consists of a gas-tight box, the interior of which is in direct communication with the gas conduits, but separated from the burner by a perforated plug, the latter having a disk closely fitting over its surface and pivoted in its centre. The disk is also perforated and is formed with a toothed edge, with which is designed to engage a pawl carried by a pliable strip. An inflatable bag is arranged to bear against the said strip, and communicates by means of a tube with a bulb, by contracting which latter the inflatable bag will cause the pawl to turn the disc.

616,288.—Air Brake. M. Corrington, New York, N. Y.

An emergency or vent valve is provided for venting the air from the train pipe. A passage is controlled by said valve and leads by one branch to the atmosphere and by another to the brake cylinder. In the former branch is located a secondary valve, while a piston chamber forms part of the branch to the brake cylinder, thus accommodating a piston for opening the secondary valve upon opening the vent valve. When the train-pipe pressure falls to a predetermined point the piston and secondary valve are returned to their normal positions.

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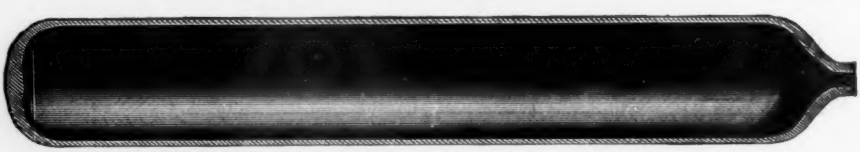

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